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Environmental toxicity potential from electricity generation in Tanzania

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Abstract
Purpose Environmental toxicity potential is the potential harm of a chemical substance or a compound that is released into the environment. Such harm is present in the generation of electricity using fossil fuels that release toxins that result in environmental pollution that would certainly have serious implications on human health and the ecosystem quality. This study assessed the environmental toxicity potential of the centralized grid-connected electricity generating systems for the years 2000, 2015, 2020, 2026 and 2030, according to the Tanzania Electricity Supply Company Limited, TANESCO's power system master plan of the year 2009.
Methods Life cycle assessment, which is a globally and widely used tool for assessing what impact product or services have during their life cycle, from production stage to disposal stage was used to assess the electricity generating systems based on process analysis. The life cycle impact assessment was calculated using CML 2001 version 2.05.
Results and discussion The results show that environmental toxicity potentials increase significantly for the years 2000, 2015, 2020, 2026 and 2030. In addition, the contribution of electricity generation from fossil fuels viz. coal, natural gas, heavy fuel and industrial diesel oils to the environmental toxicity potentials are high as compared to that of hydroelectricity.
Conclusions The result suggests that increasing the share of hydroelectricity would significantly help to reduce the environmental toxicity potentials and ultimately the environmental profile of the electricity generation could be improved.

Keywords Electricity generation · Environmental sustainability · Life cycle assessment · Sustainable development · Toxicity potential

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1 Introduction

Environmental toxicity potential is the potential harm to the environment of a chemical substance or a compound that is released into the environment (Hertwich et al. 2001). Potential harm is caused by both the absolute level of toxicity and the amount of the dose (Hertwich et al. 2001). Such harm is highly present in the generation of electricity using fossil fuels that release toxins, resulting in local as well as global pollution (Kampa and Castanas 2008) that could have severe implications on human health and ecosystems in general (Hertwich et al. 2001; Kampa and Castanas 2008; Sakulniyomporn et al. 2011). Potential damage of electricity generation using fossil fuels has raised public health concern in other countries as well (Sakulniyomporn et al. 2011).

Tanzania has 27 % of total land area as terrestrial protected areas, 8 % of territorial waters as marine protected areas, and 26 % of total territorial area as terrestrial and marine protected areas (The World Bank 2012). Although there are different causes by which species could be endangered (Table 1), e.g. by habitat destruction, illegal or unregulated killing,

Table 1 Threatened species of plants, fish and mammals (The World Bank 2012)

Indicator	2010	2011
Fish	172	174
Plants (higher)	292	290
Mammals	35	35

competition from exotic species, predation, etc., still environmental pollution has a significant contribution (The World Bank 2012). Studies have also shown that the generation of electricity has the potential impacts on human health and the ecosystem (Sakulniyomporn et al. 2011; Thanh and Lefevre 2000). Therefore, similar potential health impacts from the electricity generation can also be expected in Tanzania.

This is because electricity generation results to local pollution such as acidification in form of acid rain or dry deposition (which is caused by emission of sulphur, e.g. from coal power plants), eutrophication or nutrient enrichment (Turconi et al. 2013) that can change the pH, and the amount of dissolved oxygen (DO) in the aquatic environment as well as the depletion of natural resources including the destruction of flora and fauna (Guinée et al. 2002). In addition, release of waste waters containing heavy metals such as mercury, lead, arsenic, etc. or ammonia, chemical oxygen demand (COD), nitrate, nitrogen oxides (NO_x) and phosphate substances into the air and/or water as a result of burning of fossil fuels in power plants results to aquatic or terrestrial eutrophication in certain ecosystems (IPCC 2007; PRé 2010). Also, the emissions of methane (CH_4), dinitrogen monoxide (N_2O), and carbon dioxide (CO_2) have impact on increase in global temperature that affects the water cycle and thus can affect the growth of vegetation causing a shift in natural ecosystem balance (IPCC 2007; PRé 2010).

The economy of Tanzania basically depends on rain-fed agriculture (Byakola et al. 2009) and fisheries. Therefore, potential impact on human health and the environment would certainly affect the country's economy (Guinée et al. 2002). This is because human toxicity potential affects health of people and ultimately reduces the work force; 70 % of whom depend on agriculture (Pauw and Thurlow 2011) and quite few depends on irrigated agriculture (Mwakalila 2006). Freshwater and marine water aquatic ecotoxicity potentials would have impacts on fisheries, and the terrestrial ecotoxicity potential would have impacts on wildlife, an attraction for tourism.

Beyond a certain point, these effects would be largely irreversible and the prospect to explore future sustainable environmental profile, good human health and the balanced eco-system would be lost forever. In addition, it would certainly not be possible to achieve, by the year 2015, the seventh goal of the millennium development goals, which is "to ensure environmental

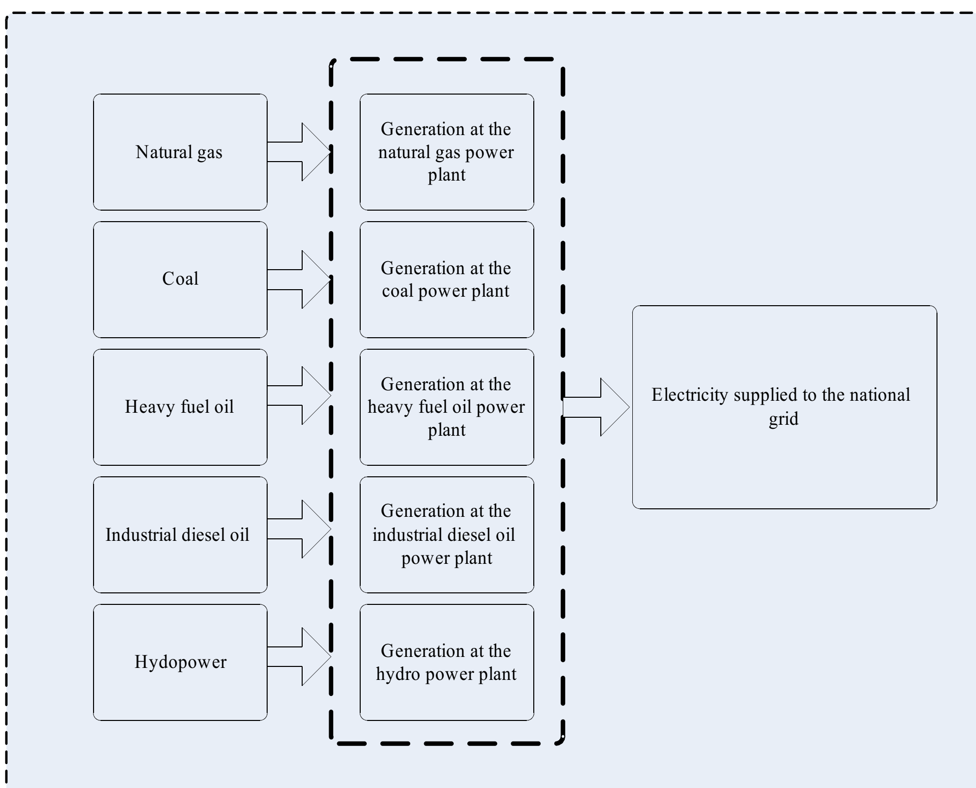

Fig. 1 Scope of the life cycle assessment of electricity generation

Table 2 Inventory, technology and efficiency factors of power plants (Felix and Gheewala 2012)

Power plant type	Technology	Efficiency (%)	Inventory (MJ)	Inventory (kg)
Natural gas	Gas engine	45	8,000	176
Natural gas	Gas turbine	42	8,571	189
Natural gas	Combined cycle	60	6,000	132
Natural gas	Open cycle	39.5	9,114	201
Coal	Fluidized bed combustor	35.5	10,141	351
Industrial diesel oil	Diesel engine	45	8,000	187
Heavy fuel oil	Fuel oil engine	45	8,000	194

Note: Hydropower technology used was falling head run-of-river and reservoir, efficiency factors 86 %. Inventory is estimated for the production of 1 MW h of electricity

sustainability" (UN 2013). It is therefore important to monitor and estimate the environmental toxicity potentials from the electricity generation that are likely to occur that would consequently cause health implications as well as other environmental implications (Turconi et al. 2013) as a result of local pollution from direct as well as indirect emissions (Kampa and Castanas 2008), wastewater effluents (Allen et al. 2011) and other toxic chemicals and substances from power generating systems (Sakulniyomporn et al. 2011).

Several studies (Coltro et al. 2003; Phumpradab et al. 2009; Schreiber et al. 2009; Weber et al. 2010; Whitaker et al. 2012) have addressed the life cycle assessment (LCA) impacts and implications associated with the production of electricity generation. However, in Tanzania, little is known about the life cycle environmental burdens associated with the country-specific electricity generation mix and technologies. The life cycle impacts of products and services in developing countries has often either been neglected or left out in the name of "development" and/or due to the lack of expertise; generally LCA studies are not considered when preparing the development master plans. Although Felix and Gheewala (2012) conducted an LCA study on electricity generation in Tanzania that addressed the environmental burdens associated with electricity generation in the context of carbon dioxide gas (CO_2) and other GHG emissions, the issue of environmental toxicity in Tanzania was not addressed. Therefore, in this publication, the issue of environmental toxicity from electricity generation in Tanzania is addressed based on a LCA.

The present study identifies and quantifies the impacts on human health and natural systems due to toxic substances emitted during electricity production. The knowledge and monitoring of the emissions of these toxic substances over time are very important in developing sustainable products and services and best generation technologies. These environmental toxicity potentials are necessary for LCAs in an attempt to make either comparative life cycle analyses or consequential life cycle analyses. Results of this paper would be of interest primarily to scholars interested in LCA databases for developing countries, specifically on the environmental toxicity caused by electricity generation.

Therefore, this paper focuses on assessing the environmental toxicity potential from the electricity generation in Tanzania. The paper addresses the following environmental toxicity potentials: human toxicity potential, freshwater aquatic ecotoxicity potential, marine water aquatic ecotoxicity potential, and the terrestrial ecotoxicity potential from year 2000 to 2015, 2020, 2026 and 2030 in Tanzania. It is anticipated that this publication has both theoretical and practical contributions to Tanzania's energy sector and could be of great help to stakeholders in developing effective and appropriate environmental management and monitoring programs as well as appropriate environmental and energy guidelines, regulations and policies, in an attempt to protect the environment and public health, more specific in supporting decision-making. This is because LCA results can be used for development and improvement of products, marketing of products, policy making and strategic planning (Heijungs et al. 2010).

Table 3 Electricity mix (%) in the national grid (Felix and Gheewala 2012)

Power plants	2000 (%)	2015 (%)	2020 (%)	2026 (%)	2030 (%)
Hydro	89	20	34	37	42
Natural gas	9	53	48	33	28
Industrial diesel oil (IDO)	2	4	3	2	2
Heavy fuel oil (HFO)	0	3	2	1	1
Coal	0	20	13	27	27
Installed capacity (MW)	782	2,160	3,460	5,160	6,160

2 Methodology

The LCA method was used as per the guidelines of ISO 14044:2006 (ISO 2006) based on process analysis. The LCA methodology is explained and discussed in detail by Wenzel et al. (1997), Azapagic (1999), Guinée et al (2002), and Finnveden et al. (2009). The life cycle impact assessment was calculated using CML 2001 version 2.05. Detailed information on CML 2001 is discussed by Guinée et al (2002). This method was chosen because it is a midpoint oriented, and based on well-debated and well-tested models, and provides wide range of characterization factors for different parts of the world such as World 1995. The method is used in many case studies published in reports and journals (Heijungs et al. 1992; Guinée et al. 2002; JRC 2010). Although there are several LCA impact assessment methods, the CML 2001 method is a widely used method (Dreyer et al. 2003; Suwanit and Gheewala 2011; Restianti and Gheewala 2012; Monteiro and Freire 2012).

2.1 Goal and scope of the study

The study quantifies the environmental toxicity potentials from electricity generating systems of the centralized grid for the years 2000, 2015, 2020, 2026 and 2030, according to the Tanzania Electricity Supply Company Limited, TANESCO's power system master plan of the year 2009. The scope of the study is shown in Fig. 1.

2.2 System boundary

In this paper, only the results of environmental toxicity potential as a result of electricity generation and expansion plans from hydropower and the fossil-based fuel sources viz. coal, natural gas, industrial diesel oil (IDO) and heavy fuel oil (HFO) are presented. Data related to efficiency factors of power plants and technologies used for electricity generation are shown in Table 2. The efficiency of the power plants built by the year 2000 are not the same as the efficiency of the power plants to be built in 2015. However, the study assumes improved power plant efficiency for years 2015, 2020, 2026 and 2030 when considering the lifetime of power plants because the power plants that are built in 2015 will be used through 2030. Furthermore, according to the power system master plan (PSMP) of 2009, there is a big change in total installed capacity of power plants in the selected time horizon.

Table 4 The HTP per MW h in the grid mix (kg DCB-eq./MW h)

Year	2000	2015	2020	2026	2030
HTP (kg DCB-eq./MW h)	50	231	170	181	170

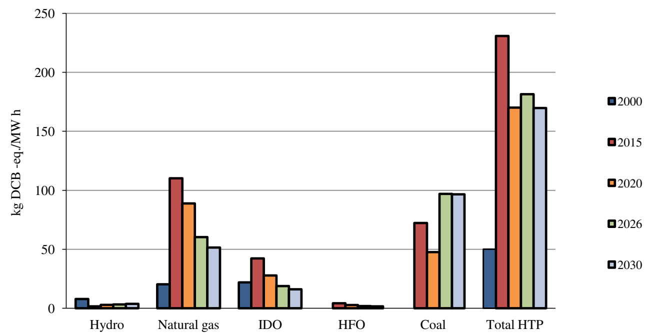

Fig. 2 Human toxicity potential (HTP) for the electricity generation in the grid mix (kg DCB-eq./MW h)

It should be noted that due to limited availability of data, the Ecoinvent version 2.2 and the U.S. Life Cycle Inventory (USLCI) version 1.6.0 databases (available in the commercial SimaPro software) had to be referred and adapted to simulate the situation in Tanzania. The Ecoinvent databases have more than 2,500 background processes with consistent, transparent and high data quality required in LCA case studies (Frischknecht and Rebitzer 2005). In addition, Ecoinvent databases allows large interlink of system of LCI unit processes with transparency (Frischknecht et al. 2005). Furthermore, the databases provide well-structured and future-oriented life cycle inventory data (Frischknecht 2005). The USLCI databases provide well-researched and well-documented data on fuel combustion required for LCA case studies for electricity production. The database unit processes related to fuels production, combustion and transportation reflect the technological advancement in electricity generation. In addition, data provided are reliable, transparent and of high quality (NREL 2004). The following databases were adopted and modified using data in Table 2: (1) electricity, hard coal, at power plant/BE U; (2) electricity, oil, at power plant/BE U; (3) electricity, hydropower, at power plant/BE U; (4) electricity, hydropower, at power plant/HR U; (5) electricity, diesel, at power plant/US U; and (6) electricity, natural gas, at power plant/ERCOT U. The selection of databases to simulate the situation in Tanzania was based on parameters such as using similar generation technology, installed and

Table 5 Contribution of each power generating system to the HTP per MW h (%)

Year	2000 (%)	2015 (%)	2020 (%)	2026 (%)	2030 (%)
Hydro	15.7	0.7	1.7	1.8	2.2
Natural gas	40.6	47.8	52.2	33.3	30.4
IDO	43.8	18.3	16.4	10.4	9.5
HFO	0	1.9	1.7	1.1	1.0
Coal	0	31.3	28.0	53.4	56.9

Table 6 The MAETP per MW h in the grid mix (tonnes DCB-eq./MW h)

Year	2000	2015	2020	2026	2030
MAETP (tonnes DCB-eq./MW h)	45	362	253	364	352

generation capacity, efficiency factors of power plants and hours of operation.

Primary data include power plants efficiency factors, installed capacity, hours of operation, electricity generation, electricity mix and types of power plants. Secondary data include part of the operational hours which was calculated using primary data and generic data.

Generic data includes stoichiometry data per megawatt-hour of electricity at the power plant based on input–output balance of mass and emissions, and have been sourced from Ecoinvent and USLCI databases. These are emissions from power plants, emissions from the processing of raw materials and fuels, and data on infrastructure processes. The assumed parameters and the selection of databases could, however, be a limitation that needs to be addressed in future LCA studies.

The study does not focus on the impact caused by building of infrastructure for natural gas-, coal- and oil-fired power plants due to the fact that contribution of infrastructure of fossil systems is usually less relevant, operation is much more relevant (Frischknecht et al. 2007). However, the following unit processes are included in the study. For IDO power plants, burning of fuel at power plant and the refinery process are included. Contribution of transportation, though very small, is included. For HFO, only processes of burning fuel at power plant are included. For coal, only coal burned in power plant is included. For natural gas, only natural gas burned in power plant is included. The study neither considered electricity consumption of the power plant nor the electricity loss due to transmission or theft.

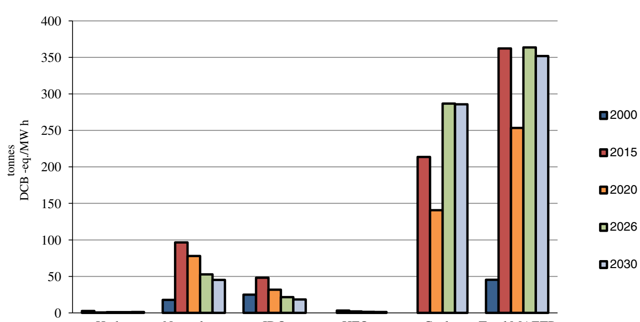

Fig. 3 Marine aquatic ecotoxicity potential (MAETP) for the electricity generation in the grid mix (tonnes DCB-eq./MW h)

Table 7 Contribution of each power generating system to the MAETP per MW h (%)

Year	2000 (%)	2015 (%)	2020 (%)	2026 (%)	2030 (%)
Hydro	5.6	0.2	0.4	0.3	0.3
Natural gas	39.3	26.7	30.7	14.5	12.8
IDO	55.1	13.3	12.5	5.9	5.2
HFO	0	0.9	0.8	0.4	0.3
Coal	0	59.0	55.5	78.8	81.2

2.3 Functional unit

The functional unit for this study is 1 MW h gross electricity generated at the power plant.

2.4 Assumptions

The key assumption is that power development will follow the 2009 PSMP for power system expansion according to the Tanzania Electricity Supply Company Limited. Estimation of electricity generation of future thermal power plants is at the average working hours (h) of 6,500 h per annum and hydropower plants at the average of 4,500 h per annum.

3 Results and discussion

3.1 Environmental toxicity potential

Environmental toxicity is an index that reflects the potential harm of a unit chemical substance or a compound that is released into the environment and thus can cause harm to the ecosystem (Hertwich et al. 2001). In this study, toxicity potential is expressed in kilograms of dichlorobenzene equivalent. In the literature, it is expressed as kilogram 1,4-DB-eq. or kilogram 1,4-DCB-eq. (Guinée et al. 2002). The 1,4-dichlorobenzene is poorly soluble in water and is not easily broken down by soil and/or aquatic organisms. In the USA, 1,4-dichlorobenzene is considered as pesticide and insecticidal fumigant (EPA 2013). Generally, toxic chemicals and substances find their way back to humans and other living organisms through various ways including direct contact and food chains (Turrio-Baldassarri et al. 2007).

The results show that the environmental toxicity potential per megawatt-hour of electricity generation from the power generation expansion plans increases within the time horizon

Table 8 The FAETP per MW h in the grid mix (kg DCB-eq./MW h)

Year	2000	2015	2020	2026	2030
FAETP (kg DCB-eq./MW h)	14	137	95	150	147

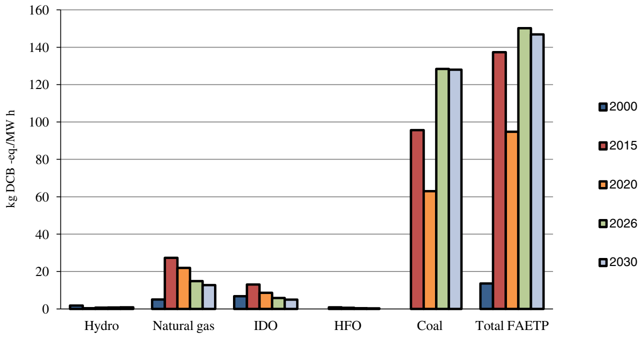

Fig. 4 Freshwater aquatic ecotoxicity potential (FAETP) for the electricity generation in the grid mix (kg DCB-eq./MW h)

from the year 2000 to 2015, 2020, 2026 and 2030 due to the increase of share of electricity generation from fossil fuels energy sources. Despite the fact that the electricity mix by 2030 will have more hydroelectricity (Table 3), the share of environmental toxicity potential from hydroelectricity is very small due to its low impact potential (Egré and Milewski 2002; Almeida et al. 2005).

Sensitivity analysis was performed to test the assumptions and parameters of the study. One of the chosen criteria for testing was "the power plant efficiency factors." The result shows that if the power plant efficiency factors are increased by 5 %, i.e. by using advanced generation technologies, the impact is reduced by 9–10 %. In addition, increasing the hour of operation of fossil fuel-based power plants increase the electricity generation and subsequently increases the impact.

3.1.1 Human toxicity potential (HTP)

The main sources of HTP are the emissions of selenium and acenaphthylene to water, and arsenic, poly-aromatic hydrocarbons (PAH), nickel, vanadium, and hydrogen fluoride to air from fossil fuel-based power plants. The HTP per megawatt-hour increases significantly from the year 2000 to 2015 and then shows stable values from 2015 to 2030 (Table 4 and Fig. 2). This is due to the reason that the electricity mix from 2015 to 2030 does not vary significantly. The highest contribution is from natural gas (2000–2030), coal (2015–2030) and IDO (2000–2020) (Table 5). Hydro has the lowest contribution (except year 2000, hydro has the highest share of electricity in the grid mix, 89 %) due to its low emission intensity (Egré and Milewski 2002; Almeida et al. 2005) and HFO shows thre lowest contribution due to its low share of electricity in the grid mix (Table 3).

Table 9 Contribution of each power generating system to the FAETP per MW h (%)

Year	2000 (%)	2015 (%)	2020 (%)	2026 (%)	2030 (%)
Hydro	13.1	0.3	0.7	0.5	0.6
Natural gas	36.9	19.9	23.1	9.9	8.7
IDO	50.0	9.5	9.1	3.9	3.4
HFO	0	0.6	0.6	0.3	0.2
Coal	0	69.7	66.5	85.4	87.1

Table 10 The TETP per MW h in the grid mix (kg DCB-eq./MW h)

Year	2000	2015	2020	2026	2030
TETP (kg DCB-eq./MW h)	0.05	0.52	0.35	0.61	0.60

3.1.2 Marine aquatic ecotoxicity potential (MAETP)

The coal and natural gas power plants show significant burden over the time period mainly due to the increase in the electricity generation from coal and natural gas-fired power plants in the grid (Table 3). However, the MAETP per megawatt-hour increases significantly from year 2000 to 2015 and then shows stable values from 2015 to 2030 (Table 6 and Fig. 3). The contribution of each power generating system to the MAETP per megawatt-hour is shown in Table 7. The contribution of hydro and IDO power plants is very small because hydro has low emission intensities (Egré and Milewski 2002; Almeida et al. 2005) compared to other technologies while IDO (except for the year 2000) and HFO have the lowest share in the grid mix. The main contributor to this impact category is the emission of hydrogen fluoride (to air), and that of selenium, vanadium, barium and barite (to water) from the operation of heavy fuel oil, and coal power plants.

3.1.3 Freshwater aquatic ecotoxicity potential (FAETP)

The FAETP per megawatt-hour increases significantly from the year 2000 to 2015 and become stable from 2015 to 2030 (Table 8 and Fig. 4) with the highest contribution from coal (2015–2030), natural gas (2000–2020) and IDO (2000)

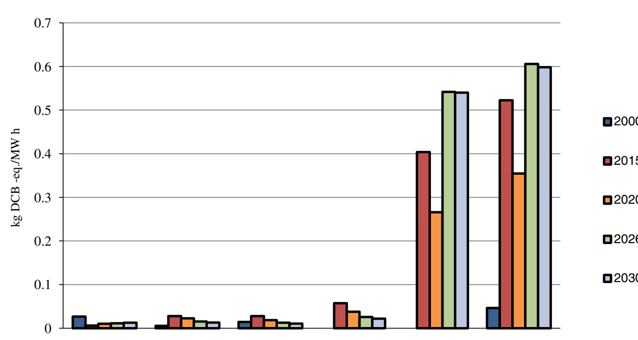

Fig. 5 Terrestrial ecotoxicity potential (TETP) for the electricity generation in the grid mix (kg DCB-eq./MW h)

Table 11 Contribution of each power generating system to the TETP per MW h (%)

Year	2000 (%)	2015 (%)	2020 (%)	2026 (%)	2030 (%)
Hydro	57.4	1.2	2.9	1.8	2.1
Natural gas	11.6	5.3	6.3	2.5	2.2
IDO	31.0	5.3	5.2	2.1	1.8
HFO	0	11.0	10.6	4.2	3.7
Coal	0	77.3	75.0	89.4	90.3

(Table 9). Hydropower has the lowest contribution due to its low emission intensity (Egré and Milewski 2002; Almeida et al. 2005) and HFO show a lowest contribution due to its low share of electricity in the grid mix. The major contribution to this impact category is the emissions of nickel, acenaphthylene, beryllium, vanadium and barium (to air and water) from fossil fuel-based power plants.

3.1.4 Terrestrial ecotoxicity potential (TETP)

The TETP per megawatt-hour increases significantly from the year 2000 to 2015 and then the values stabilizes from 2015 to 2030 (Table 10 and Fig. 5) with the highest contribution (Table 11) in decreasing order from coal (2015–2030), natural gas (2000), IDO (2000), and hydro (2000, due to its high share of its electricity in the grid mix, Table 3). The emission of heavy metals such as mercury, chromium, nickel and vanadium from fossil fuel-based power plants has a significant burden to this impact category. Hydro (2015–2030) has the lowest contribution due to its low emission intensity (Egré and Milewski 2002; Almeida et al. 2005) as well as low share in the grid mix (as compared to 2000) and HFO show a lowest contribution due to its low share of electricity in the grid mix.

3.2 Environmental impact intensities

Environmental impact intensities per megawatt-hour of this study are compared to that of Mexico and Nigeria (Table 12). The two countries were chosen because they have almost similar electricity generation characteristics including electricity generation technologies, power plant emission factors, time of operation and the electricity mix. In addition, like for this study, the LCA studies for Nigeria and Mexico have followed the ISO 14044:2006 guidelines.

The main essence of this comparison is to show how "electricity mix" in the grid can affect the per megawatt-hour impact of electricity generated. The comparison found that the environmental toxicity potential of this study is in the same order of magnitude with the environmental toxicity potential from Mexico and Nigeria (Gujba et al. 2010, 2011; Santoyo-Castelazo et al. 2011). This suggests that similar electricity generation characteristics have similar emission characteristics as well.

The slightly difference between the values of Tanzania and Nigeria is due to their slightly differences in power plant efficiency factors, electricity mix and the type of technology used for the electricity generation. Mexico has about 80 % of the electricity from fossil fuels (2006), with the remaining electricity from hydro, geothermal, wind and nuclear; thus, the environmental toxicity potential for Mexico are higher than that of Tanzania and Nigeria (Santoyo-Castelazo et al. 2011).

Mexico and Tanzania have roughly the same order of magnitude for the HTP, FAETP and MAETP for the years 2020–2030 where the electricity mix of Tanzania has about 66 % fossil and 34 % hydro (Table 3; Table 12). This suggests that the higher the share of fossil fuels for the electricity generation, the higher the environmental toxicity potential.

Nigeria has about 60 % of the electricity generated from hydro, with the remaining electricity from thermal power plants; therefore, its environmental toxicity potential are lower than the environmental toxicity potential of Tanzania (Gujba et al. 2010, 2011).

From the above comparison, the levels of environmental toxicity potentials for the three countries are high and can damage human health and the ecosystem. Therefore, they should be dealt with by encouraging more sustainable and environmental friendly generation technologies.

3.3 Implication of the results

Metals are the main source of atmospheric metal pollution during the burning of fossil fuels (Nriagu 1990). Exposure to heavy metals such as lead (Pb), arsenic (As) cadmium (Cd) and mercury (Hg) poses a serious problem to human health and the ecosystem (Järup 2003) because they tend to bio-

Table 12 Comparison of environmental toxicity potential for this study with Mexico (Santoyo-Castelazo et al. 2011) and Nigeria (Gujba et al. 2010; Gujba et al. 2011)

Country	Year	HTP (kg DCB-eq./MWh)	FAETP (kg DCB –eq./MWh)	MAETP (kg DCB-eq./MWh)	TETP (kg DCB-eq./MWh)
Tanzania	2000	50	14	45,371	0.05
Tanzania	2015	231	137	362,335	0.52
Nigeria	2003	41	2	4,904	0.07
Mexico	2006	601	83	682,399	21.00

accumulate in the human body (Kampa and Castanas 2008). Therefore, appropriate measures must be taken to reduce their levels in the environment, and ultimately, the human health risk will be reduced and the environmental profile will be improved.

Since the country has well-established terrestrial and marine protected areas (The World Bank 2012), it is therefore important to monitor and reduce any potential risks to the protected areas. One such strategy is to minimize emissions from various sources including power plants.

The contamination of heavy metals to consumable food crops such as maize which is the main cereal crop grown and consumed in the country (Marwa et al. 2012) poses potential health risks to millions of people and animals. Through bioaccumulation and biomagnification, these toxic substances find their way up the food chain from one trophic level to another.

In addition, the country depends on agriculture; therefore, potential contamination of heavy metals in agricultural produce would result to the rejection of the produce in local, regional as well as international markets. This would have a negative effect on the country's gross domestic product (GDP), economy and sustainable development (WCED 1987).

4 Conclusions

The result shows an increase in environmental toxicity potential within the time frame mainly due to increase in the share of electricity generation from fossil fuels. From the study, fossil fuel-based power plants have higher contribution of impacts per megawatt-hour. This suggests that the proposed power system master plan would have significantly higher environmental toxicity potential that would certainly have serious implications on environmental profile and the public health. However, there is still an opportunity for electricity sector in Tanzania to have better environmental profile compared to what is presented herein, only if environmental-friendly and sustainable generation technologies are fully deployed.

By reducing the share of electricity generation and/or increasing the power plant efficiency factors of fossil fuel-based power plants and increasing the share of hydroelectricity would help to reduce the environmental toxicity potentials from the electricity generation, and thus the potential risk of environmental impacts that would have negative impact on environment and the public health would certainly be reduced.

In addition, it is recommended that before irreversible change occurs and to achieve a sustainable future environmental profile of electricity generation, power plants technologies with high generating efficiency, and hydroelectricity be encouraged. Furthermore, the hydroelectricity generation potential is still huge, estimated at 4,700 MW (Mwakapugi et al. 2010); however, it needs to be fully developed by utilizing available resources in a timely and sustainably manner. Nevertheless, there might be limitation of funds for hydroelectricity development plans but proper financial mechanisms could be established. Furthermore, since this study had to rely much on secondary data, there is scope for improving the results in future studies.

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